

THE SENSITIVENESS OF THE EYE TO LIGHT AND COLOUR.¹

THERE may be some here who have had the pleasure—or the pain—of rising very much betimes in a Swiss centre of mountaineering in order to gain some mountain peak before the sun has had power enough to render the intervening snow-fields soft, or perhaps dangerous. Those who have will recollect what were the sensations they experienced as they sallied out of the comfortable hotel, after endeavouring to swallow down breakfast at 2 a.m., into the darkness outside. Perhaps the night may have been moonless, or the sky slightly overcast, and the sole light which greeted them have been the nervous glimmer of the guides' lanterns. By this feeble light they may have picked their way over the stony path, and between the frequent stumbles over some half hidden piece of rock lying in the short grass they may have had time to look around and above them, and notice that the darkness of the night was alone broken by stars which gave a twinkle through a gap in the clouds, or if the sky were cloudless, every star would be seen to lie on a very slightly illuminated sky of transparent blackness. Although giant mountains may have been immediately in front of them, their outlines would be almost if not quite invisible. As time went on the sky would become a little brighter, and what is termed the *petit jour* would be known to be approaching. The outlines of the mountains beyond would become fairly visible, the tufts of grass and the flowers along the path would still be indistinguishable, and most things would be of a cold grey, absolutely without colour. The guide's red woollen scarf which he bound round his neck and mouth would be black as coal. But a little more light, and then some flowers amongst the grass would appear as a brighter grey, though the grass itself would still appear dark; but that red scarf would still be as black as a funeral garment. The mountains would have no colour. The sky would look leaden, and were it not for the stars above it might be a matter of guesswork whether it were not covered over with cloud.

More light still, and the sky would begin to blush in the part where the sun was going to rise, and the rest would appear as a blue-grey; the blue flowers will now be blue, and the white ones white; the violet or lavender coloured ones will still appear of no particular colour, and the grass will look a green grey, whilst the guide's neck-gear will appear a dull brown.

The sun will be near rising, the white peaks beyond will appear tipped with rose; every colour will now be distinguished, though they would still be dull; and, finally, the daylight will come of its usual character, and the cold grey will give place to warmth of hue.

But there may be others who have never experienced this early rising, and prefer the comfort of an ordinary English tramp to that just described; but even then they may have felt something of the kind. In the soft autumn evening, when the sun has set, they may have wandered into the garden and noticed that flowers which in the daytime appear of gorgeous colourings—perhaps a mixture of red and blue—in the gloaming will be very different in aspect. The red flowers will appear dull and black; a red geranium, for instance, in very dull light, being a sable black, whilst the blue flowers will appear whitish-grey, and the brightest pale yellow flowers of the same tint; the grass will be grey, and the green of the trees the same nondescript colour. A similar kind of colouring will also be visible in moonlight when daylight has entirely disappeared, though the sky will have a transparent dark blue look about it, approaching to green. These sensations, or rather lack of sensations of light and

colour, which as a rule attract very little attention, as they are common ones, are the subjects of my discourse to-night.

Experiments which can be shown to a large audience on this subject are naturally rather few in number, but I will try and show you one or two.

We are often told that the different stages of heat to which a body can be raised are black, red, yellow, and white heat, but I wish to show you that there is an intermediate stage between black and red heat, viz. a grey heat. An incandescent lamp surrounded by a tissue paper shade, has a current flowing through it, and in this absolutely dark room nothing is seen, for it is black hot. An increase of the current, however, shows the shade of a dim grey, whilst a further increase shows it as illuminated by a red, and then a yellow light. A bunch of flowers placed in the beam of the electric light shows every colour in perfection; the light is gradually dimmed down, and the reds disappear, whilst the blue colours remain and the green leaves become dark. These two experiments show that there is a colour, if grey may be called a colour, with which we have to reckon.

Now the question arises whether we can by any means ascertain at what stage a colour becomes of this grey hue, and at what stage of illumination the impression of mere light also disappears, and whether in any case the two disappear simultaneously.

As all colours in nature are mixed colours, it is at the outset useless to experiment with them in order to arrive at any definite conclusion, hence we are forced—and the forcing in this direction to the experimentalist is a very agreeable process—we are forced to come to the spectrum for information.

The apparatus on this table is one which I have before described in this theatre, and it is needless for me to describe it again. I can only say that it has in all colour investigations been of such service that any attempt on my part to do without it would have been most disadvantageous. The apparatus enables a patch of what is practically pure monochromatic light of any spectrum colour to be placed upon the screen at once, and an equally large patch of white light alongside it, by means of the beam reflected from the first surface of the first prism.

It should be pointed out that this beam of white light reflected from the first prism of the apparatus, having first passed through the collimator, must of necessity diminish with the intensity of the spectrum, when the collimator slit is closed.

Having got these patches, the next step is to so enfeeble the light that their colour and then their visible illumination disappear.

An experiment which well demonstrates loss of colour is made by throwing a feeble white light on one part of the screen, and then in succession patches of red, green, and violet alongside it. The luminosity of the coloured light gradually diminishes till all the colour disappears, the white patch being a comparison for the loss of colour.

If red, green, and violet patches be placed alongside each other, and they are bedimmed in brightness together, it will be noticed that the red disappears first, then the green, and then the violet; or I may take a red and green patch overlapping, which when mixed form orange, and extinguish the colour: the slit allowing red light to fall on the screen may be absolutely closed, and no alteration in the appearance of the patch is found to occur. This shows, I think, that when all colour is gone from a once brilliant colour, a sort of steel-grey remains behind, and that red fails to show any luminosity when the green still retains its colour.

The measurement of the extinction of colour from the different parts of the spectrum was made on these prin-

¹ A Lecture delivered at the Royal Institution of Great Britain by Captain W. de W. Abney, C.B., R.E., D.C.L., F.R.S.

ciples. A box, similar to Fig. 2, was prepared, but having two apertures, one at each side. Through one the coloured ray was reflected, and through the other a white

out for the ordinates; each curve is therefore made on a scale ten times that of its neighbour, counting from the centre.

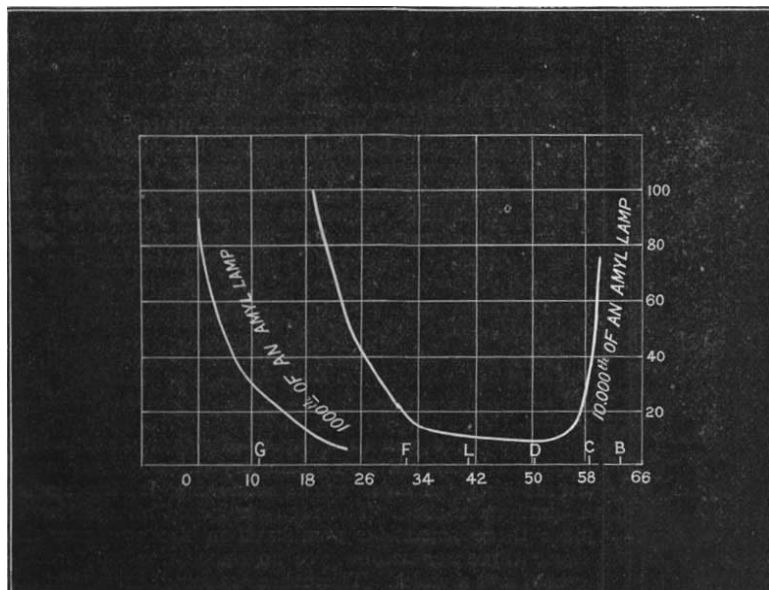


FIG. 1.—Extinction of Spectrum Colours.

beam of light to a white screen. Both beams were diminished, and when the white and coloured patches appeared the same hue, the amount of illumination was calculated. Fig. 1 shows graphically the reduction of illumination, when the D light of the spectrum is the same intensity as one amyl-acetate lamp at one foot from the screen. To measure the extinction of light, a box was made as in the diagram, closed at each end, but having two apertures as shown, Fig. 2:—E is a tube through which the eye looks at S, which is a black screen with a white spot upon it, and which can be illuminated by light coming through the diaphragm D first falling on a ground glass which closes the aperture, and reflected on to it by M a mirror.

The patch of light of any colour being thrown on D, rotating sectors, the apertures of which could be opened and closed at pleasure, were placed in the path of the beam, thus enabling the intensity of the patch to be diminished. D could be made of any desired aperture, and thus the illumination of the ground glass would be diminished at pleasure. After keeping the eye in darkness for some time, the eye was placed at E, when the white spot illuminated by the colour thrown on D was visible, and the sectors closed till the last scintilla of light was extinguished. This was repeated for rays at different parts of the spectrum, and the results are shown in Fig. 3 by the continuous curved lines. The diagram would have been too large had the same scale been adopted through-

means of a double reflection of the beam forming the patch from one or two plain glass mirrors, and also by using a plain glass mirror in the box instead of a silvered glass. By this plan the light falling on the first plain glass mirror was reduced, before it reached the end of the box, 1000 times; and again, by narrowing the slit of the collimator, and also the slit placed in the spectrum,

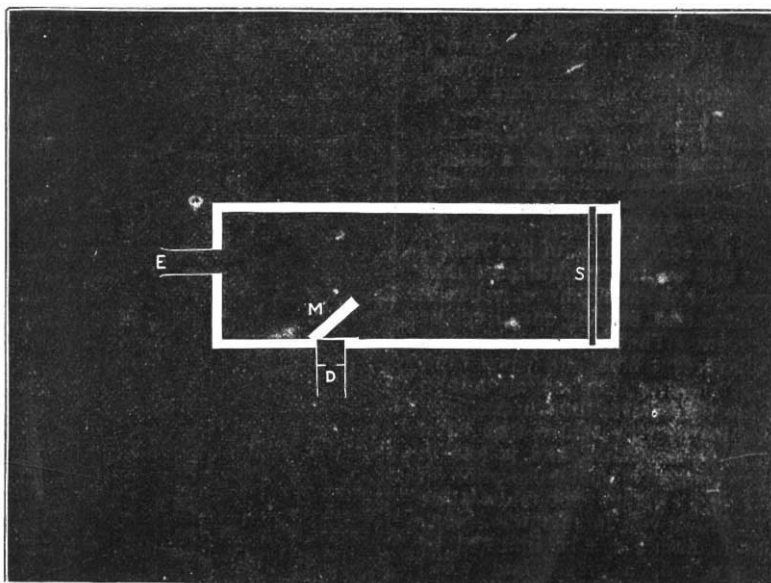


FIG. 2.—Extinction Box.

another similar reduction would be effected. All rays thus enfeebled were within the range of extinction. It was found that neither ground glass nor rotating sectors

In the diagram the sodium light of the spectrum before extinction was made of the luminosity of the amyl-acetate lamp (hereafter called AL), which is about .8 of a standard candle, at 1 foot distance from the source. Before it ceased to cause an impression on the eye, the illumination had to be reduced

to $\frac{350}{10,000,000}$ A L.

E light	to	$\frac{65}{10,000,000}$	
F light	„	$\frac{150}{10,000,000}$	or $\frac{15}{1,000,000}$
G light	„	$\frac{3000}{10,000,000}$	or $\frac{3}{10,000}$
C light	„	$\frac{11,000}{10,000,000}$	or $\frac{11}{10,000}$
B light	„	$\frac{70,000}{10,000,000}$	or $\frac{7}{1000}$

Of its spectrum luminosity.

had any prejudicial effect, and therefore this extinction curve may be taken as correct.

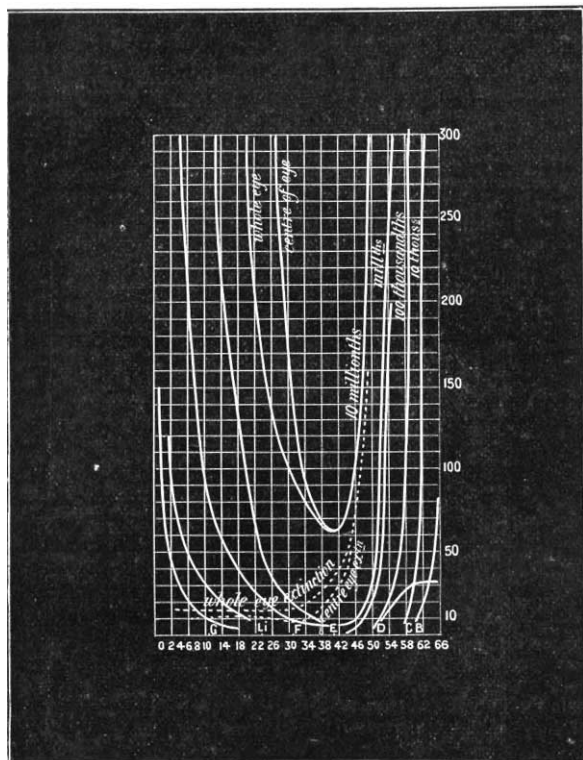


FIG. 3.—Extinction of the Spectrum.

In the curves there are two branches at the violet side, and this requires explanation. One shows the extinction when viewed by the most sensitive part of the eye, wherever that may be, and the other when the central portion of the eye was employed. The explanation of this difference in perception is chiefly as follows:—

In the eye we have a defect—at least we are apt to call it a defect, though no doubt Providence has made it for a purpose—in that there is a yellow spot which occupies some 6° to 8° of the very centre of the retina, and as it is on this central part that we receive any small image, it has a very important bearing on all colour experiments. The yellow spot absorbs the blue-green, blue, and violet rays, and exercises its strongest absorption towards the centre, though probably absent in the very centre, that is, in the "fovea centralis," and is less at the outer edges. That absorption of colour by the yellow spot takes place can be shown you in this way. Any colour in nature can be imitated by mixing a red, a green, and violet together, and with these I will make a match with white and then with brown, two very representative colours, if we may call them colours. Now if I, standing at this lecture table, match a white by mixing these three colours together, using

a large patch, the image will fall on a part of the retina of considerably larger area than the yellow spot, and it will appear too green for those at a distance; but it is correct for myself. If I place a mirror at a distance, and make a match again by the reflected image, the match is complete for us all, as we all see it through the yellow absorbing medium. If I look at it direct from where I stand the match is much too pink. It may be asked why the comparison patches and the mixed colours do not always match since both images are received on the same part of the retina. The reason is that the green I have selected for mixture is in the part of the spectrum where great absorption takes place, whilst the comparison white contains the green of the whole spectrum, some parts of which are much less absorbed than others. I may remark that just outside the yellow spot the eye is less sensitive to the red than is the centre, and this is one additional cause of the difference. See Fig. 5.

More on this subject I have not time to say on this occasion, but it will be seen that the extinction of light for the centre and the outside of the eye differs on account of this.

I must take you to a theory of colour vision which, though it may not be explanatory of everything, at all events explains most phenomena—that is, the Young-Helmholtz theory. The idea embodied in it is that we have three *sensations* stimulated in the eye, and that these three sensations give an impression of a red, a green, and a violet. These three *colours* I have said can be mixed to match any other colour, or, in other words, the three sensations are excited in different degrees, in order to produce the sensation of the intermediate spectrum colours, and those of nature as well.

The diagram Fig. 4 shows the three sensations as derived from colour equations made by Koenig. It will be seen that there are three complete colour sensations, all of which are present in the normal eye. I would ask you to note that at each end of the spectrum only one sensation is present, viz. at the red end of the spectrum, the red sensation, and at the violet end the violet.

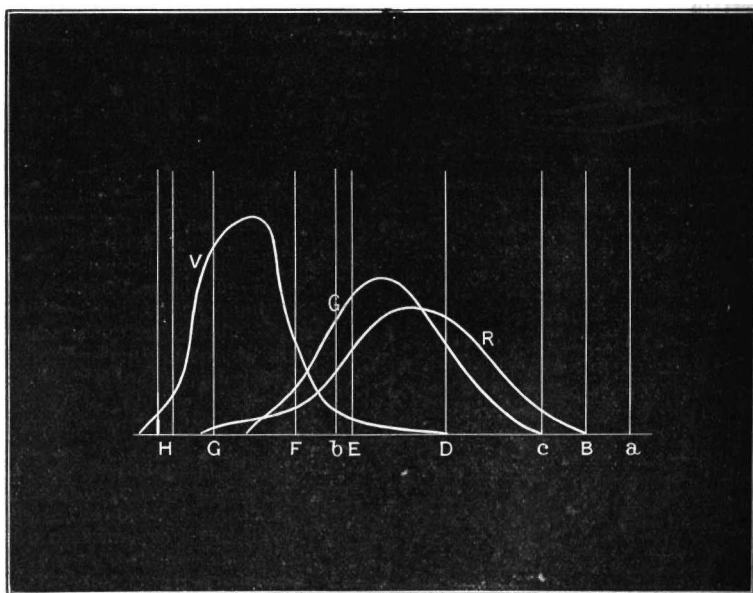


FIG. 4.—Colour Sensations.

This is a matter of some importance, as we shall now see.

It will be recollected that in making the extinctions, the D light of the spectrum was made equal to one amygdalate lamp, and the other rays had the relative luminosity to it, which they had in the spectrum before they were extinguished. The luminosity curve of the spectrum is shown in Fig. 5.

Suppose we make all the luminosities of the different rays equal to one A L., we should not get the same extinction value, as shown in the continuous lines in Fig. 3. The violet would have to be much more reduced, but by multiplying the extinction by the luminosity we should get the curve of reduction for equal luminosities, and we get the dotted curves in Fig. 3.

It will be seen that it is the violet under such circumstances that would be the last to be extinguished, and that all the rays at the violet end of the spectrum would be extinguished simultaneously, as would also those at the extreme red. This looks like a confirmation of the Young-Helm-

This being so, I think it will be pretty apparent that, at all events from the extreme violet to the Fraunhofer line D of the spectrum, the extinction is really the extinction of the violet sensation, a varying amount of which is excited by the different colours. If then we take the reciprocals of the numbers which give extinction of the spectrum, we ought to get the curve of the violet sensation on the Young-Helmholtz theory. For if one violet sensation has to be reduced to a certain degree before it is unperceived, and another has to be reduced to half that amount, it is evident that the violet sensation must be double in one case to what it is in the other; that is, the degrees of stimulation are expressed by the reciprocal of the reduction.

Such a curve is shown in Fig. 5 (in which also are drawn the curves of luminosity of the spectrum when viewed with the centre of the retina and outside the yellow spot). And it will be noticed that it is a mountain which reaches its maximum about E. Remember that the height of the curve signifies the amount of stimulation given to the violet sensory apparatus by the particular ray indicated in the scale beneath.

Turning once more to Fig. 3, it will be noticed that if any one or two of the three sensations are absent, the persons so affected are, what is called, colour-blind. Thus if the red sensation is absent, they are red-blind; if the green, then green-blind; if the violet, then violet-blind; if both red and green sensations are absent, then the person would see every colour, including white, as violet. The results of the measurement of the luminosity of the spectrum by persons who have this last kind of monochromatic vision should be that they give a curve exactly or at all events very approximately, of the same form as the curve given by the reciprocals of the extinction curve obtained by the normal eye, as the violet sensation is that which is last stimulated.

It has been my good fortune to examine two such persons, and I find that this reasoning is correct, the two

coinciding when the curves for the centre of the retina are employed.

Further, I examined a case of violet blindness, and measured the luminosity of the spectrum as apparent to him. Now if the Young-Helmholtz theory be correct, then in his case the violet sensation ought to be absent, and the difference between his luminosity and that of the normal eye ought to give the same curve as that of the violet sensation. This was found to be the case.

Again, the reciprocal of the extinction curves of the red-blind and green-blind ought to be the same as those of the normal eye, for the violet sensation must be present with them also. This was found to be so. We have still one more proof that the last sensation to disappear is the violet.

If we reduce the intensity of the spectrum till the green and red disappear to a normal eye, and measure the luminosity of the spectrum in this condition, we shall find that it also coincides with the persistency curve. On the screen we have a brilliant spectrum, but by closing the slit admitting the light and placing the rotating sectors in the spectrum and nearly closing the apertures, we can reduce it in intensity to any degree we like. The whole spectrum is now of one colour and indistinguishable in hue from a faint white patch thrown above it. If the luminosity of this colourless spectrum be measured we

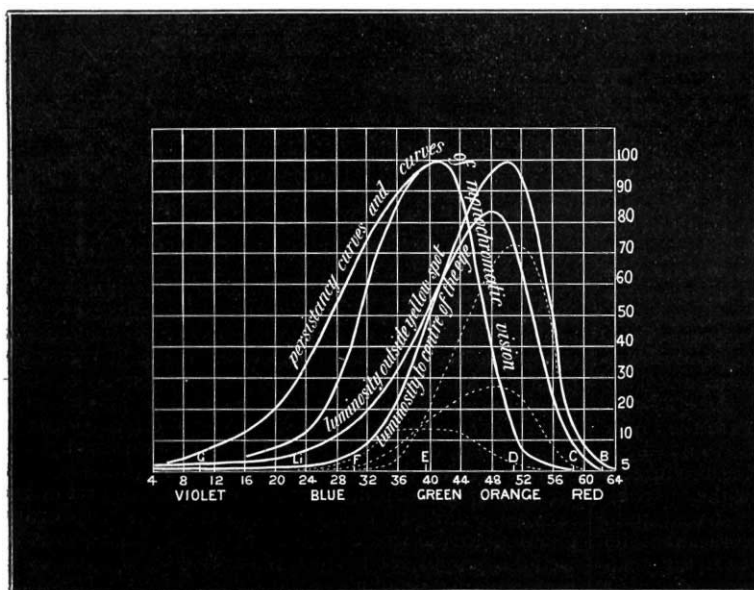


FIG. 5.

holtz theory which I have briefly explained, for we cannot imagine that it can be anything but a single sensation which fails to be excited.

The violet is extinguished when it is $\frac{15}{10,000,000}$ A L., that is, a screen placed 817 feet away and illuminated by an A L. violet lamp would be invisible. The blue-green (F) light when it is $\frac{17}{10 \text{ millionths}}$ or 770 feet away.

The green (E) light $\frac{35}{10 \text{ millionths}}$ or 550 feet away. The orange (D) light is extinguished as before at $\frac{350}{10 \text{ millionths}}$ or 180 feet away, whilst the red (C) light has only to be reduced to $\frac{2200}{10 \text{ millionths}}$ or an A L. lamp radiating C light would have to be placed only 67 feet away, whilst the radiation for an A L. of the colour of the B light of the spectrum would have to be diminished to but $\frac{2600}{10 \text{ millionths}}$ or the screen would have to be placed 60 feet away.

It is therefore apparent that with equal luminosities the violet requires about 175 times more reduction to extinguish it than does the red, and probably about 25 times more than the green.

shall get the result stated. The curve obtained in this way is in reality identical with the other curves. By these four methods then we arrive at the conclusion that the last colour to be extinguished is the sensation which when strong gives the sensation of violet, but which when feeble gives a blue-grey sensation.

One final experiment I may show you. It has been remarked that moonlight passing through painted glass windows is colourless on the grey stone floor of a cathedral or church.

We can imitate the painted glass and moonlight. Here is a diaper pattern of different coloured glasses, and by means of the electric light lantern we throw its coloured pattern on the screen. The strength of moonlight being known, we can reduce the intensity of the light of the lamp till it is of the same value. When this is done it will be seen that the pattern remains, but is now colourless, showing that the recorded observations are correct, and I think you are now in a position to account for the disappearance of the colour.

I have now carried you through a series of experiments which are difficult to carry out perfectly before an audience, but at any rate I think you will have seen enough to show you that the first sensation of light is what answers to the violet sensation when it is strong enough to give the sensation of colour. The other sensations seem to be engrafted on this one sensation, but in what manner it is somewhat difficult to imagine. Whether the primitive sensation of light was this and the others evolved, of course we cannot know. It appears probable that even in insect life this violet sensation is predominant, or at all events existent. Insects whose food is to be found in flowers seek it in the gloaming, when they are comparatively safe from attack. Prof. Huxley states that the greater number of wild flowers are certainly not red, but more or less of a blue colour. This means that the insect eye has to distinguish these flowers at dusk from the surrounding leaves, which are then of a dismal grey; a blue flower would be visible to us whilst a red flower would be as black as night. That the insects single out these flowers seems to show that they participate in the same order of visual sensations. I venture to think, without adopting it in its entirety, that these results at all events give an additional probability as to the general correctness of the Young-Helmholtz theory of colour vision. Where the seat of colour sensation may be is not the point, it is only the question as to what the colour sensations make us feel which the physicist has to deal with. The simpler the theory, the more likely is it to be the true one, and certainly the Young-Helmholtz theory has the advantage over others of simplicity.

"THE EPIGLOTTIS."¹

FROM an anthropotomical point of view the epiglottis had for a long time been generally looked upon as a kind of sentinel for the protection of the upper air-passages, when Rückert's comparative anatomical observations showed that the human epiglottis greatly differed from that of mammals, in so far as its relations to the soft palate were entirely altered, and that its physiological conditions *pari passu* had undergone important modifications. The new points of view thus obtained induced Gegenbaur to study the comparative anatomy of the epiglottis and its relations to the larynx, and the present volume is the outcome of his investigations.

The inquiry being undertaken from a morphological point of view the author begins with a study of the different forms of the epiglottis or epiglottoid structures in low classes of animal life. He next discusses the mammalian epiglottis and its relations to the soft palate. The con-

clusions here arrived at, and which concern the act of deglutition in the lower classes of mammals, lead to a consideration of other organs of the oral cavity, and to an attempt at establishing a connection between these and the apparatus consisting of the epiglottis and soft palate. This in turn induces a minute investigation of the structure of the epiglottis, and of its relationship to the framework of the larynx and the general structure of the respiratory organs in the lowest forms of animal life. In the last chapter the author summarizes the results obtained by his comparative studies and throws out such suggestions concerning the origin, development, and function of the epiglottis as would seem justified by his researches.

Brief as this survey of the course of Gegenbaur's essay necessarily has been, it will be sufficient to show that it is quite impossible to give in the space of a short review a detailed analysis of its contents. Conclusions derived from the synthetic conception of an enormous number of single observations, which extend over a large part of the entire animal kingdom, can only be properly appreciated by a study of the original, and this may be warmly recommended.

The final and most important conclusion arrived at by the author may be briefly summarized as follows:—

Whilst as high up in the scale as in the sauropsidæ, parts of two branchial arches only contribute towards forming the primary hyoid, three more arches are added in the mammals. Two of these growing together form the transition into the thyroid, which becomes intimately connected with the larynx.

The mammalian larynx, however, has received a further addition, viz. the epiglottis, the cartilage of which can only be looked upon as the further development of the fourth branchial arch, which in fishes still serves its primitive function, and in the amphibia appears in a rudimentary form. The exact manner in which this rudiment passes over into the supporting organ of the epiglottis in mammals is, on the whole, still obscure. So much, however, is certain, that the cartilage of the epiglottis is not a product of mucous membrane, but a genuine part of the skeleton, and that it communicates its supporting function to the whole of the epiglottis, which serves as well the purpose of keeping the air-passages open as of protecting the vestibule of the larynx.

From this final conclusion it will be seen that, according to Gegenbaur, the rôle of the epiglottis in its highest development is purely a respiratory and protective one.

Pathological observation in man does not admit of these functions of the part being looked upon in any way as indispensable for the existence of the individual. Total loss of the epiglottis has often been observed in various diseases, without the patients either suffering from dyspnoea or from increased liability to the entrance of foreign bodies into the lower air-passages, the *constrictor vestibuli laryngis* (Luschka) in such cases vicariously taking its function. The supposed phonatory rôle of the epiglottis, upon which much stress is laid by some eminent singing masters (e.g. Stockhausen), inasmuch as they maintain that it influences, according to its more erect or more horizontal position, the "timbre" of the singing voice, is not even mentioned in Gegenbaur's essay. Thus many points connected with this subject still demand elucidation. Still it is impossible to withhold the expression of admiration and of gratitude to the author of the present work for his patient and extensive researches in a very obscure field of comparative anatomy.

NOTES.

ON Saturday the British Eclipse Expedition to West Africa arrived safely at Bathurst. The *Alecto* was there, ready to convey the party up the Salum River to the selected site.

¹ "Die Epiglottis," Vergleichend anatomische Studie, by Carl Gegenbaur, with two plates, &c. (Leipzig: Wihl. Engelmann, 1892.)